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ESTIMATING THE PROBABILITY OF A LARGE FALL IN TEMPERATURE AT WASHINGTON, D. C.

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ABSTRACT

Three criteria based on the surface pressure distribution at 0130 E. S. T. are developed for large falls in temperature from the 0130 E. S. T. temperature to the minimum the following night. For those cases which meet all three criteria, charts are developed based on temperature gradients and pressure gradients which give probabilities of large falls in temperature ranging from less than 10 percent to greater than 90 percent. Forecasts are made for those cases in which the probability is 50 percent or greater, and compared with the official Weather Bureau forecasts for the same cases.

CONTENTS

INTRODUCTION

One purpose of this paper is to present and illustrate a particular type of technique, or approach, to a specific forecasting problem. The approach is based mainly upon the techniques developed and used by Brier in developing objective methods of forecasting the occurrence of precipitation at Washington, D. C. [1], and precipitation amounts in the TVA Basin [2]. Other investigators have used similar procedures on other forecasting problems. For example: Thompson [3], in forecasting precipitation amounts at Los Angeles, Vernon [4], in forecasting occurrence of precipitation 24 to 48 hours in advance at San Francisco, Penn [5], in forecasting precipitation amounts for Boston, and Palmer [6], in forecasting the direction of movement of low pressure centers.

The specific problem attacked in this investigation was the forecasting of large falls in temperature from one night to the next during the winter months at Washington, D. C. The objective has been to determine the synoptic situations which are most likely to be followed by a large drop in temperature and to develop a basis for probability statements regarding such an occurrence. This work has been a continuation of the research on minimum temperature forecasting at Washington, D. C., begun by the Weather Bureau in 1946. A report on the research conducted prior to the present work is contained in Weather Bureau Research Paper No. 27 entitled "Objective Methods of Forecasting Winter Minimum Temperatures at Washington, D. C.," by Conrad P. Mook and Saul Price.

At first glance there would seem to be no connection between the "Trajectory Method" as described by Mook and Price and the procedures outlined in the following pages, but the basic idea behind the "Trajectory Method" has been retained, if somewhat simplified. The "Trajectory Method" is a technique for forecasting the "source" of the surface air which will be over the station at the end of the forecast period. The procedures described in this report, however, do not attempt to forecast the exact source, but rather attempt to group into one class those situations in which advection is from the same general direction and which include as many as possible of the large drops in temperature.

The criteria for a large drop in temperature which were developed in this study were based on data from the winter months of January, February, and December of the years 1940 through 1943 inclusive and January and February 1944. Minimum temperatures for Washington, D. C., which occurred between 1930 E. S. T. and 0730 E. S. T. were obtained from Weather Bureau Forms 1001. All other temperature and pressure data were taken from the analyzed 0130 E. S. T. surface maps. A total of 414 cases were obtained from these 14 months. Data for seven days were not obtainable due to the 0130 E. S. T. maps being missing from the series used. The dates of these days are January 20 to 24 inclusive, 1940; December 1, 1940; and January 16, 1941. The data for these 414 cases or any portion of them will be referred to as "original" data.

Data from the twelve winter months of December 1944 through February 1948 were obtained from the same sources as above and reserved for test purposes. Data were available for every day in these months making a total of 361 cases. These data will be referred to as "test" data.

DEVELOPMENT OF CRITERIA FOR A LARGE DROP IN TEMPERATURE

As stated in the introduction, the primary objective was to determine the synoptic situations which are most likely to be followed by a large drop in temperature, and to develop a basis for probability statements regarding such an occurrence. For the purpose of this paper, a large change in temperature is defined as a change of 10 Fahrenheit degrees or more from 0130 E. S. T. one day to the minimum temperature occurring between 1930 E. S. T. and 0730 E. S. T. the following night. Depending upon the time of occurrence of the minimum, this constitutes an 18- to 30-hour forecast. In general the forecast is for 24 to 30 hours, since normally the minimum temperature occurs between 0130 E. S. T. and 0730 E. S. T. In what follows, a "10° drop" will mean a fall in temperature of 10° or greater. Similarly a "15° drop" will mean a fall in temperature of 15° or greater, and a "20° drop" a fall of 20° or greater.

In this study no attempt has been made to discover or introduce anything new into forecasting temperature changes. Instead, some of the more obvious things on the surface chart which every forecaster considers in making a temperature forecast have been combined systematically to arrive at a probability statement of the occurrence of a large drop in temperature.

Most large falls in temperature occurring in the middle latitudes result from distinct changes of air mass over the station. This implies the passage of a cold front. Approximately 90 percent of falls in temperature (as defined above) of 20° or greater which occur at Washington, D. C., result from a cold front passage. Changes of 10° to 20°, however, frequently result from a different type of situation. This is the case of a well developed low pressure center, usually an east coast cyclone, which passes to the south or east of the station with a subsequent influx of cold air from the north to northwest.

DEVELOPMENT OF CRITERION 1

Since the position of the low center with respect to the station is of primary importance in connection with a large change in temperature, whether a cold front is involved or not, the first variable investigated was the position of the point of lowest pressure which lay between 70° and 100° W, long., and 30° and 55° N. lat. on the 0130 E. S. T. surface charts. The temperature change as defined above was plotted on a base map of North America at the position of the lowest pressure within this area. While a definite separation of large positive and large negative changes could be detected, it was apparent from inspection of some of the surface maps for individual cases that the area chosen was much too large.

The area was therefore reduced to that bounded by the 75th and 95th meridians, and the 30th and 45th parallels of latitude. The point of lowest pressure within this area was then located and temperature changes plotted for only those cases in which the temperature change was plus or minus 10° F. or greater (fig. 1). In order to avoid bounding this area each time it is mentioned, it will henceforth be referred to simply as the "area."

Figure 1 shows a good discrimination between large negative and large positive changes, and is the basis of the first criterion for a large drop in temperature.

Criterion 1.—

The position of lowest pressure in an area bounded by the 75th and 95th meridians and the 30th and 45th parallels of latitude must be east or south of a line as indicated on figure 1.

In the 414 cases of original data there were 97 cases of 10° drops, or a probability of 0.23. By applying Cri-

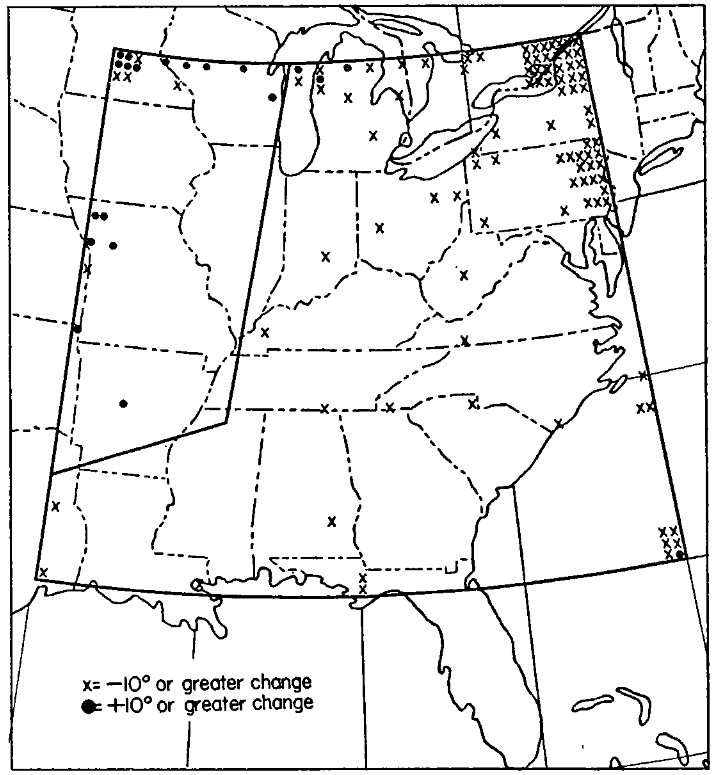

FIGURE 1.—Map showing position of lowest pressure in the area bounded by the 75th and 95th meridians and the 30th and 45th parallels of latitude for only those cases in which the change in temperature from 0130 E. S. T. to the minimum the following night was 10° F. or greater.

terion 1 the original 414 cases were separated into two groups in which the probability of a 10° drop in one group was 0.32 ($^{92}/_{292}$), and in the other only 0.04 ($^{5}/_{122}$). The second of these groups was then eliminated and only the 292 cases of the first group considered for further study.

DEVELOPMENT OF CRITERION 2

Inspection of the 0130 E. S. T. surface charts after which a drop of 10° or more occurred, showed as was mentioned above, that in a large proportion of the cases the change was caused by a cold front passage at Washington. Furthermore, in nearly every case the cold front existed either between Norfolk, Va., and Chicago, Ill., or between Norfolk and Alpena, Mich., depending upon the orientation of the front. Usually the cold front was oriented in a northeast-southwest position, so that the front was between Norfolk and both Chicago and Alpena. Cases occurred, however, where the front was oriented in such a way that it lay between Chicago and Alpena, and thus existed only between Norfolk and Alpena, or only between Norfolk and Chicago, depending upon whether the front had an east-west or north-south orientation. A further distinction will be made between these two cases later. Norfolk was chosen as the eastern bounding position of the cold front instead of Washington itself to allow for those cases in which Washington was still in the transition zone of the front at 0130 E. S. T. and the initial large drop in temperature had not taken place. A front to the east of Norfolk was in general far enough to the east of Washington so that Washington was no longer in the transition zone.

A cold front as described above existed in 83 of the 292 cases which satisfied Criterion 1. Fifty-four, or 65 percent of these 83 cases resulted in a 10° drop in temperature. From these figures the first part of Criterion 2 was formulated: (*a*) A cold front must exist between Norfolk and Chicago, or between Norfolk and Alpena, Mich., depending upon the orientation of the front.

In the 209 cases in which no cold front existed it was found that the cases were distributed in such a way that 74 percent of the 10° drops occurred when the point of lowest pressure in the "area" fell south of 42½° N. A proportionally greater number of 10° drops occurred when the point of lowest pressure fell south of 42½° N. than when it fell north of 42½° N. This distribution is illustrated in table 1. From this distribution the second part of Criterion 2 was formulated: (*b*) If no cold front exists, the point of lowest pressure in the area must be south of 42½° N.

Table 1.—*Distribution of falls in temperature of 10° or greater with latitude of point of lowest pressure in the "area"*

Latitude of lowest pressure	Total cases	Number of 10° drops	Percent
30–32	59	11	19
33–34	16	3	19
35–37	21 }120	6 }28	29 }23
38–39	5	1	20
40–42	19	7	37
43–45	89	10	11

As can be seen from table 1, in 89 cases the point of lowest pressure was north of 42½° N. of which 10 cases were 10° drops. The most successful variable found for further stratifying these 89 cases was the current 0130 E. S. T. temperature at Washington. Figure 2 shows a scatter diagram of temperature change plotted against the 0130 E. S. T. Washington temperature. In 8 of the 10 cases which had a drop of 10° the Washington temperature was 40° F. or greater, while in only 6 of the 79 cases which had less than a 10° fall was the Washington temperature 40° or greater. From this chart the third part of Criterion 2 was formulated: (*c*) If no cold front exists and the point of lowest pressure in the "area" is north of 42½° N. the 0130 E. S. T. Washington temperature must be greater than 39° F.

The three parts are assembled to form the second criterion for a large drop in temperature at Washington, D. C.

Criterion 2.—

(*a*) A cold front must exist between Norfolk and Chicago, or between Norfolk and Alpena, Mich., depending upon the orientation of the front.

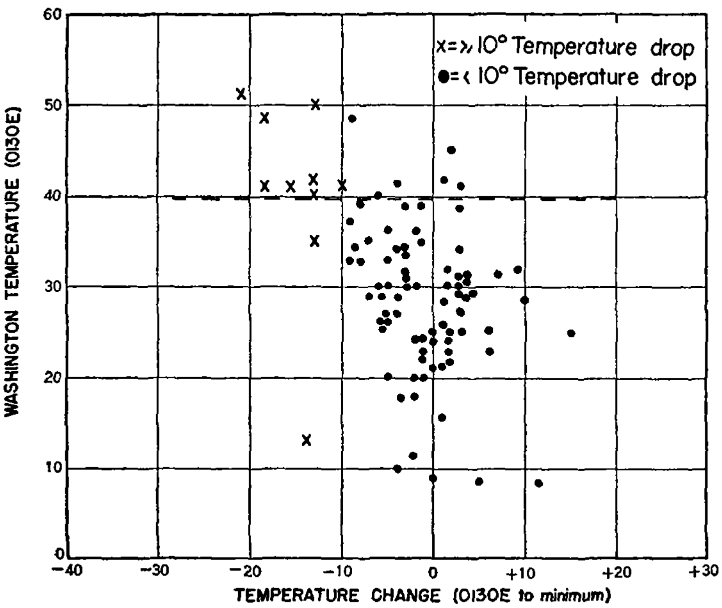

Figure 2.—Graph showing temperature change plotted against the 0130 E. S. T. Washington temperature for all cases which satisfied Criterion 1, and in which the point of lowest pressure in the "area" was north of 42½° latitude, and in which no cold front existed between Norfolk and Chicago, or between Norfolk and Alpena, Mich.

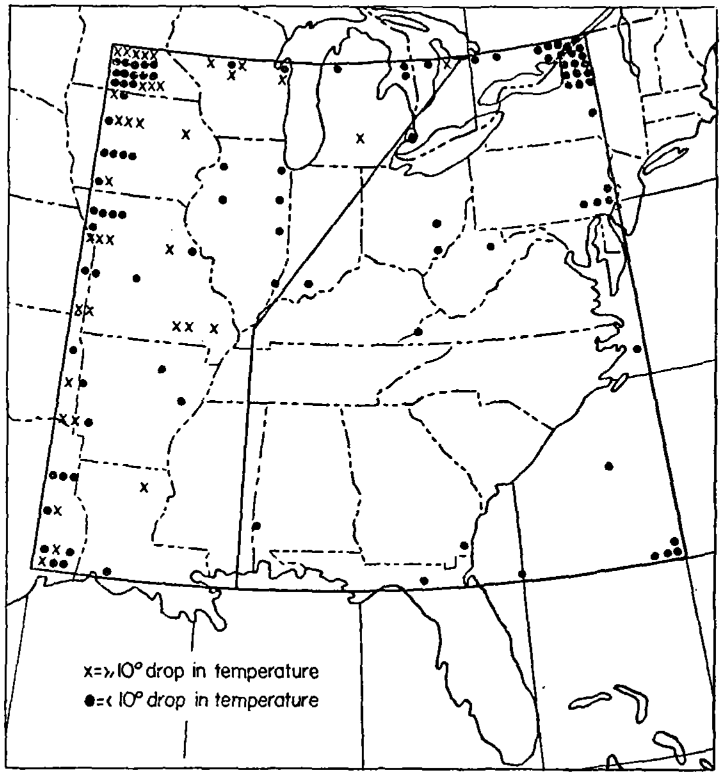

Figure 3.—Map showing position of highest pressure in the "area" for all cases which met Criteria 1 and 2, but in which no cold front existed between Norfolk and Chicago or between Norfolk and Alpena.

(*b*) If no cold front exists, the point of lowest pressure in the area described in Criterion 1 must be south of 42½° N. latitude.

(*c*) If no cold front exists, and the point of lowest pressure is north of 42½° N. latitude, the 0130 E. S. T. temperature at Washington must be greater than 39° F.

Criterion 2 applied to the 292 cases which satisfied the first criterion resulted in a separation into two groups in which the probability of a 10° drop in one was 0.41 ($\frac{90}{217}$), and only 0.03 ($\frac{2}{75}$) in the other. Here again the second group was eliminated and only the 217 cases which met both criteria were retained for futher study.

DEVELOPMENT OF CRITERION 3

To obtain further criteria for a drop of 10° or more, the point of highest pressure in the "area" was examined. In using this variable, it was found that better results could be obtained by again separating the cases according to whether or not a cold front existed as described under Criterion 2. The position of highest pressure in the "area" did not show a significant separation of 10° drops from other cases in the "cold front" cases. This variable did, however, eliminate a large proportion of cases which did not drop 10° from the "no cold front" cases. Figure 3 shows the temperature change plotted at the point of highest pressure in the "area" for only those cases which met the first two criteria, but in which no cold front existed between Norfolk and Chicago or between Norfolk and Alpena.

The third criterion for a large drop in temperature was then formulated from this chart.

Criterion 3.—

(*a*) Same as Criterion 2 (*a*).

(*b*) If no cold front exists, the point of highest pressure in the area described under Criterion 1 must be west of the line drawn on figure 3.

Applying Criterion 3 to the 217 cases which met the first two criteria resulted in a separation into two groups in which the probabilities of a 10° drop were 0.51 (90/175) and 0.00 (0/42). Again, the second group was eliminated and the 175 cases of the first group retained for further study.

APPLICATION OF ALL THREE CRITERIA

The results obtained by applying all three criteria to the original 414 cases are summarized in table 2 and figure 4. From table 2 it is seen that the three criteria eliminate 73 percent (232/317) of those cases which do not fall 10° or more, while retaining 93 percent (90/97) of those cases which result in a 10° drop in temperature. Figure 4 is a summary of the application of each criterion to the data, showing how the probability of a 10° or greater drop is increased as each criterion is applied.

TABLE 2.—*Contingency table showing the relationship between the observed temperature fall and the 3 criteria for a large fall in temperature. Values are from "original data"*

Observed temperature drop	Meets criteria 1, 2, and 3		
	Yes	No	Total
≥10°	90	7	97
<10°	85	232	317
Total	175	239	414

CRITERION 1 No. 10° Drops / No. Cases	%	CRITERION 2 No. 10° Drops / No. Cases	%	CRITERION 3 No. 10° Drops / No. Cases	%
(a) 92/292	32	(a) 90/217	41	(a) 90/175	51
				(b) 0/42	0
		(b) 2/75	3		
(b) 5/122	4				

(a) - Indicates that the criterion is satisfied.

(b) - Indicates that the criterion is not satisfied.

FIGURE 4.—Table illustrating how the probability of a large fall in temperature is increased as each criterion is applied to the cases which satisfied the previous criterion. Values are from "original" data.

At this point it might be recalled that one of the purposes of the foregoing procedures was to group into one class those situations in which the advection of air into Washington was from the same general direction, while at the same time including as many as possible of the large falls in temperature. As shown above, the procedure retains 93 percent of the large drops. Figure 5 shows the distribution of the temperature changes in the 175 cases of original data which met all three criteria. In 90 percent of the cases (157/175) there was a drop in temperature, while in only 10 percent (18/175) was the change zero or a rise in temperature. Better methods of determining whether cold air advection occurred might be devised, but if the assumption is made that a drop in temperature,

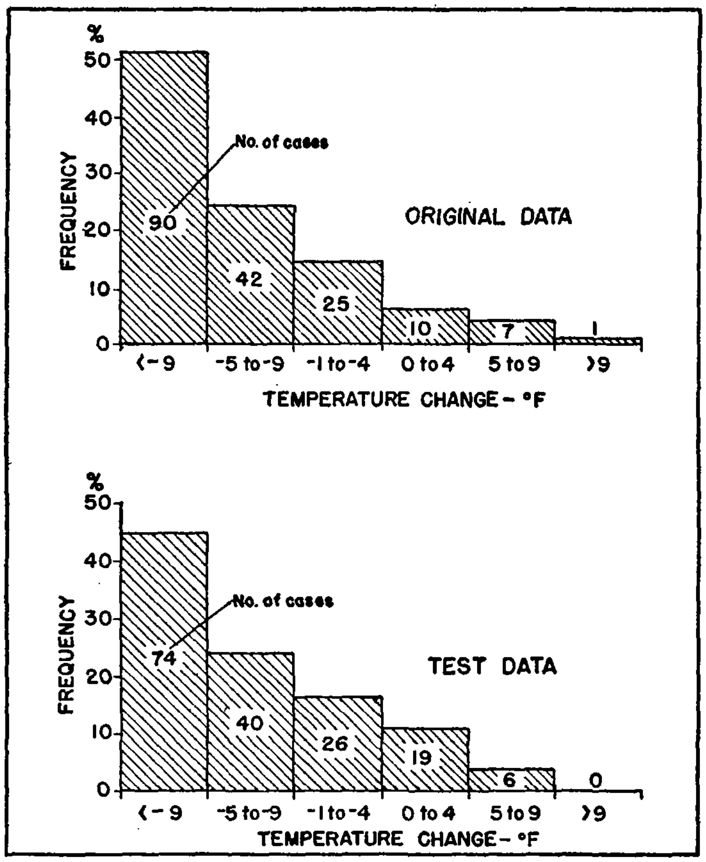

FIGURE 5.—Chart showing frequency distributions of temperature change from 0130 E. S. T. to the minimum the following night in those cases which satisfied all three criteria for a large fall in temperature.

regardless of magnitude, indicates cold air advection, in general from a northwesterly direction, this distribution indicates that cold advection took place in a large majority of the cases.

TEST OF CRITERIA ON INDEPENDENT DATA

Obviously, the results presented thus far could be expected to be good since the charts upon which the criteria were based were drawn in such a way as to give the maximum results. Before proceeding with further study of the cases which met the three criteria, it would be well to determine how well the criteria hold up on independent data which were not used in determining them.

For this purpose the 12 months of "test" data described in the introduction were used. The criteria were applied to the daily 0130 E. S. T. surface maps and the proportion of the 10° drops to the total number of cases which met each criterion were noted as in the "original" data. The results of this test are summarized in table 3 and figure 6. Comparing figures 6 and 4 it is seen that there is very little difference between the percentages from the "original" data and the "test" data.

TABLE 3.—*Contingency table showing the relationship between the observed temperature fall and the 3 criteria for a large fall in temperature. Values are from "test data"*

Observed temperature drop	Meets criteria 1, 2, and 3		
	Yes	No	Total
≥10°	74	9	83
<10°	91	187	278
Total	165	196	361

Table 3 shows that of the 361 cases of "test" data, 83 or 23 percent had a drop in temperature of 10° or greater—the same percentage as in the "original" data. Of the 278 cases that did not have a 10° drop, 187 or 67 percent were eliminated as compared with 73 percent in the "original" data. Of the 83 cases which had a drop of 10°, 74 or 89 percent met the three criteria, as compared with 93 percent in the original data. Application of the three criteria to the 361 "test" cases results in a sample of 165 cases in which the probability of a 10° drop is 45 percent, as compared with the climatological probability of 23 percent.

From the standpoint of whether the criteria group together cases in which the advection is that of cold air, the distribution of temperature changes in the 165 test cases which met all three criteria show that 85 percent (140/165) had falls in temperature, while only 15 percent (25/165) had zero change or a rise in temperature. This distribution is shown in figure 5.

CRITERION 1 No. 10° Drops / No. Cases	%	CRITERION 2 No. 10° Drops / No. Cases	%	CRITERION 3 No. 10° Drops / No. Cases	%
(a) $\frac{80}{252}$	31	(a) $\frac{77}{196}$	39	(a) $\frac{74}{165}$	45
				(b) $\frac{3}{31}$	9
		(b) $\frac{3}{56}$	5		
(b) $\frac{3}{109}$	4				

(a)- Indicates that the criterion is satisfied.

(b)- Indicates that the criterion is not satisfied.

FIGURE 6.—Table illustrating how the probability of a large fall in temperature is increased as each criterion is applied to cases which satisfied the previous criterion. Values are from "test" data.

DEVELOPMENT OF PROBABILITY CHARTS FOR CASES WHICH MET ALL THREE CRITERIA

TEN-DEGREE DROPS

Except for Criterion 2(c), the criteria are based upon the distribution of pressure and location of cold fronts on the 0130 E. S. T. surface chart. An additional stratification of cases which satisfy the three criteria may be based upon some measure of the temperature gradient and some measure of the strength of flow of air during the forecast period.

A number of temperatures and temperature gradients measured in various directions to the north and northwest of Washington were tried with varying degrees of success in further stratifying the 175 cases of original data which met the three criteria. The combination which gave the most satisfactory distribution of 10° falls was the temperature difference between Wasnington and Fort Wayne plotted against the Washington temperature—except for cases in which Fort Wayne was just to the east or south of a cold front. For the cases in which the cold front was oriented in a north-south direction and lay between Fort Wayne and Chicago, the temperature at Milwaukee was substituted for the Fort Wayne temperature. For the cases in which the cold front had an east-west orientation and lay between Fort Wayne and Alpena, the temperature at a point behind the front on a line normal to the front from Washington, at a distance equal to that between Washington and Fort Wayne was substituted for the Fort Wayne temperature.

Using the temperature difference between Washington and Fort Wayne (or the temperature difference as described above when appropriate) as one coordinate and the Washington temperature as the other, the temperature change at Washington was plotted at the point determined by these two variables. Probabilities of a 10° drop in temperature were then computed by noting the proportion of points representing the 10° drops to the total number of points in various areas over the chart. Isopleths of these computed probabilities were then drawn resulting in the pattern shown in figure 7.

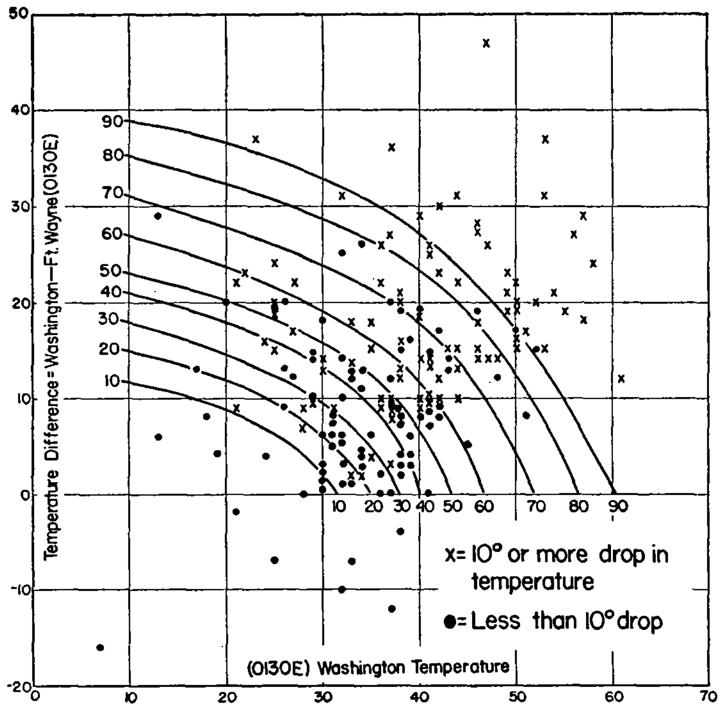

FIGURE 7.—Graph showing isopleths of probability of a 10° or greater fall in temperature based on the temperature difference between Fort Wayne and Washington at 0130 E. S. T. and the Washington 0130 E. S. T. temperature.

For a measure of the strength of flow expected during the forecast period, pressure differences were computed from the 0130 E. S. T. surface chart as indicated in figure 8. These indices are taken somewhat to the west of the station, to try to account for the general west to east movement of pressure systems, and they are oriented so as to obtain the maximum pressure differences when northwest or southwest flows are indicated. Pressure differences were computed for each of the 175 cases of original data that met the three criteria for a large drop in temperature. Using these pressure differences, or indices, as coordinates the temperature change was plotted, probabilities of a 10° drop computed, and isopleths drawn resulting in the pattern in figure 9.

For each of the 175 cases two probabilities of a 10° fall were obtained from figures 7 and 9. Using these two probabilities as coordinates the temperature change was again plotted at the point determined by each pair of probabilities. Probabilities of a 10° drop were again computed on this new chart and isopleths of probabilities drawn resulting in figure 10. Figure 10 gives the final estimate of the probability of a drop in temperature of 10° or more from 0130 E. S. T. to the minimum temperature the following night.

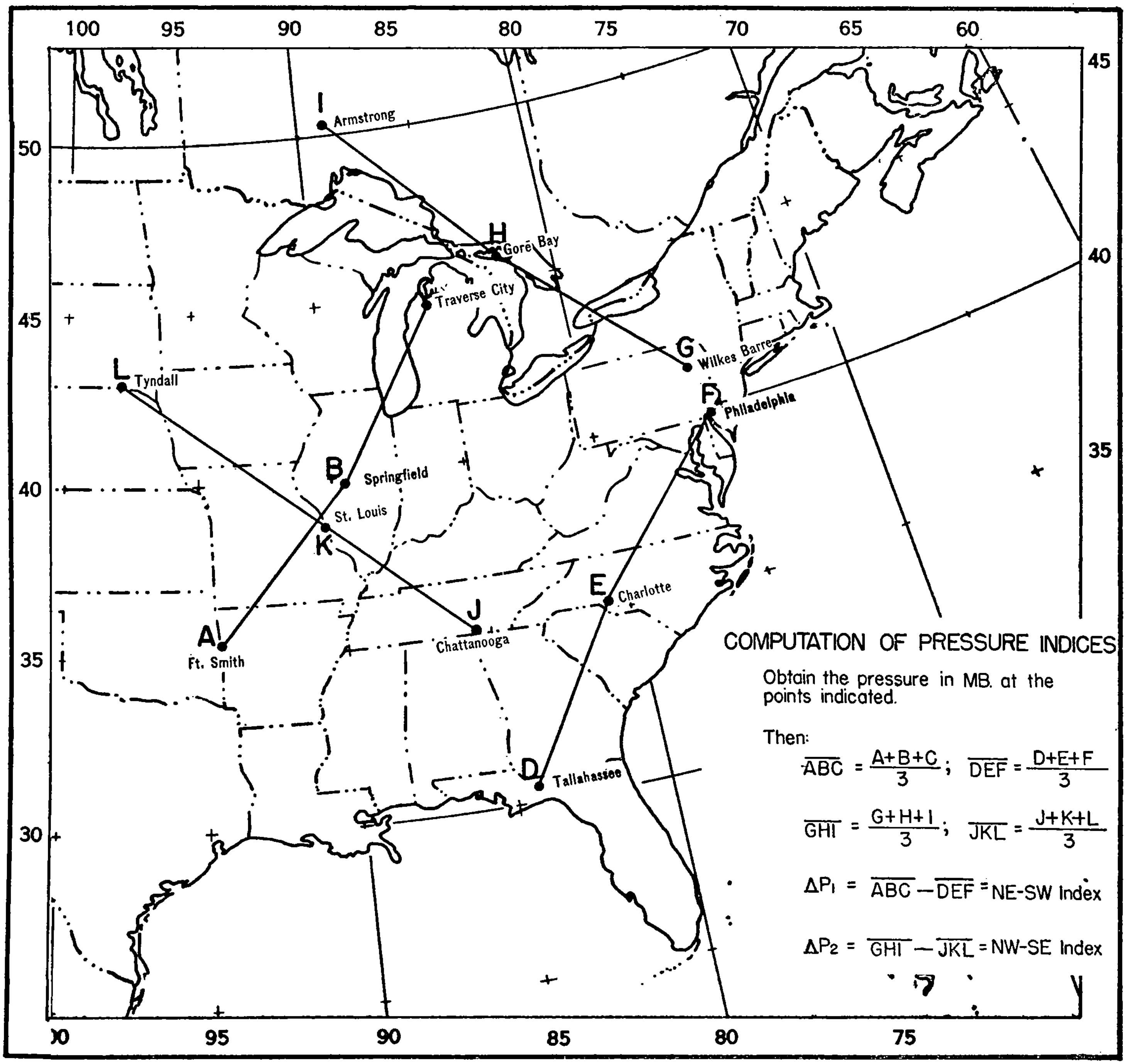

FIGURE 8.—Map showing location of points at which pressures are obtained for computing the pressure indices, ΔP_1, and ΔP_2.

The ability of figure 10 to forecast, or express, a correct probability of a 10° drop in temperature was tested on the 165 cases of "test" data which met the three criteria for a large fall in temperature. For each case the 0130 E. S. T. temperature at Washington and the temperature difference between Washington and Fort Wayne were obtained. If the case was one in which Fort Wayne was just east or south of a cold front, the temperature difference as described above was obtained instead of the temperature difference between Washington and Fort Wayne. Entering figure 7 with these two variables, a probability of a 10° drop was obtained. Pressure indices were computed for each case by the method illustrated in figure 8. Figure 9 was entered with these pressure differences and a second probability obtained. Entering figure 10 with the probabilities from figures 7 and 9, a final probability of a 10° drop was obtained for each of the 165 cases.

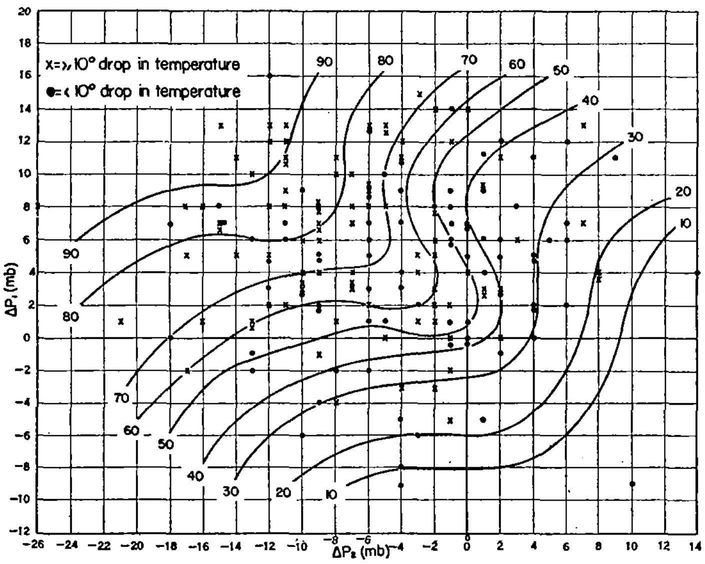

FIGURE 9.—Graph showing isopleths of probability of a 10° or greater drop based on pressure indicies computed by method shown in figure 8.

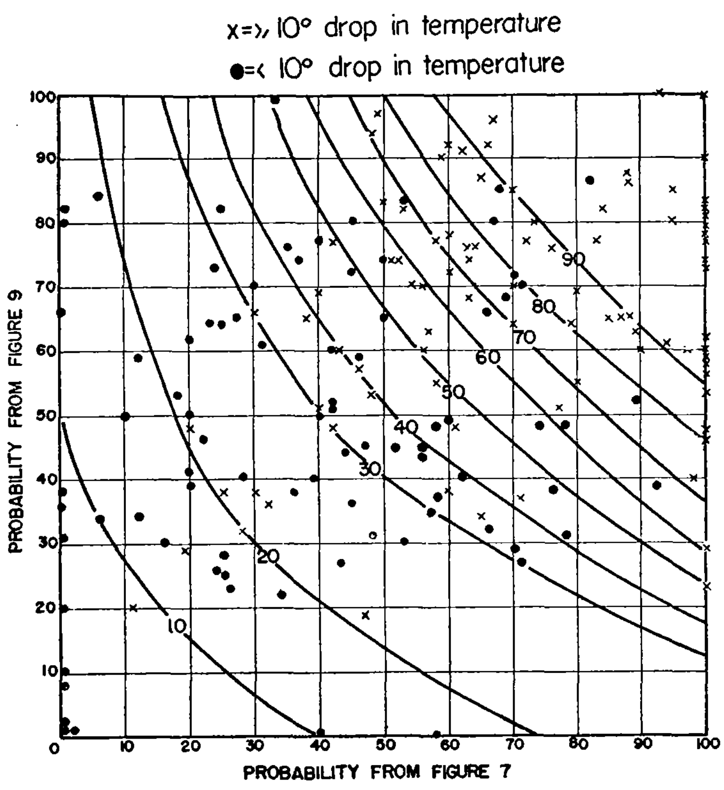

FIGURE 10.—Joint probability chart combining probabilities obtained from figures 7 and 9. Isopleths show probability of drop of 10° or greater.

In table 4 these probabilities were grouped according to five class intervals, and the number of 10° drops which would be expected in each class was compared with the observed number of 10° drops in each class.[1] Thus, for example, 32 cases were found for which the probability obtained from figure 10 lay in the 40–59 percent group. The number of 10° drops which might be expected to fall in this group is 16 (50 percent of the 32 cases). The number of 10° drops observed in this group was 15.

TABLE 4.—*Comparison of expected and observed number of 10° drops in class intervals of computed probability of 10° drops. Values are from "test data"*

Class intervals of objectively estimated probability of a 10° drop in temperature (percent)	Number of cases in each class	Approximate number of 10° drops expected in each class	Number of observed 10° drops in each class
0–19	25	2	1
20–39	52	16	9
40–59	32	16	15
60–79	19	13	18
80–99	37	33	31

FIFTEEN DEGREE DROPS

Exactly the same variables were used in constructing charts for 15° drops as were used for 10° drops. The temperature changes of the 175 cases of original data were again plotted using the Washington temperature and the temperature differences between Washington and Fort Wayne as coordinates for one chart (fig. 11) and the pressure indices computed from figure 8 as coordinates for

[1] A Chi square test was made of the consistency between the distribution of the expected number of 10° drops and the distribution of the observed number. These data do not reject the hypothesis that the frequencies in the independent data are from the same population as the frequencies on which the computed probabilities are based.

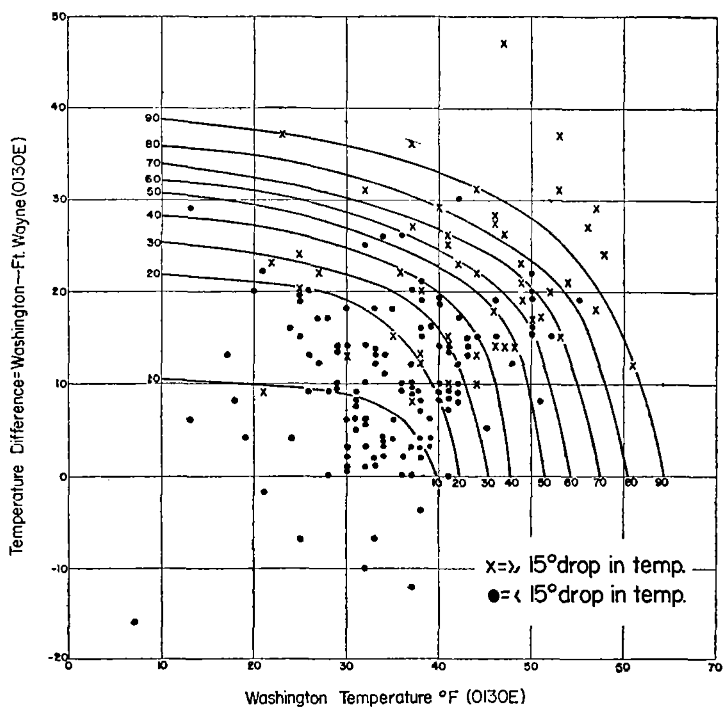

FIGURE 11.—Graph showing isopleths of probability of a 15° or greater drop in temperature based on the 0130 E. S. T. temperature difference between Fort Wayne and Washington and the Washington 0130 E. S. T. temperature.

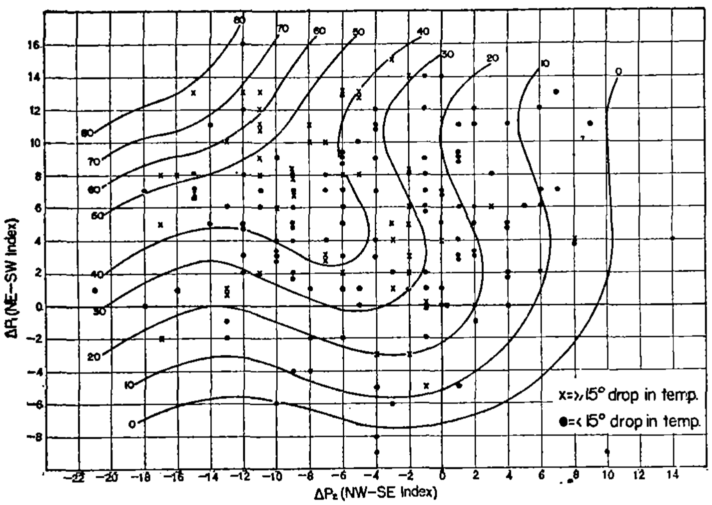

FIGURE 12.—Graph showing isopleths of probability of a 15° or greater drop based on pressure indices computed by method shown in figure 8.

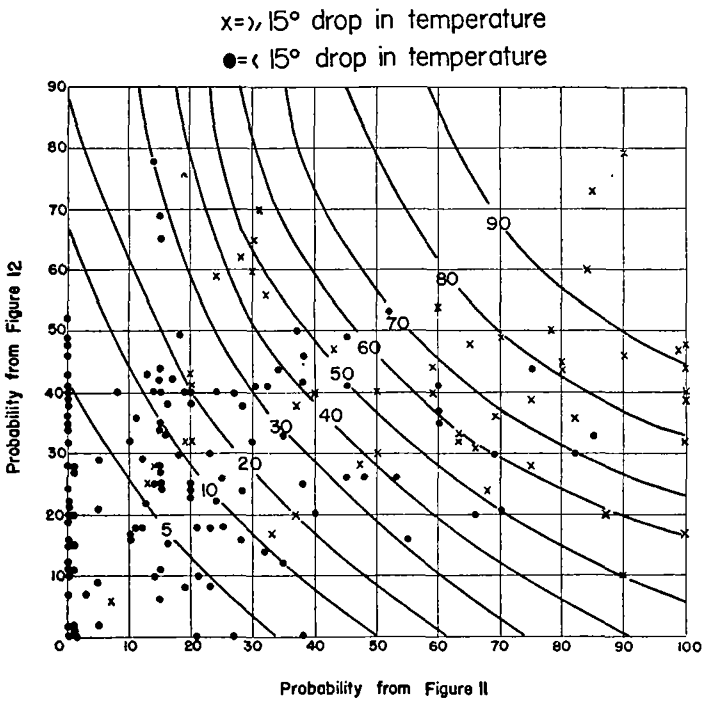

FIGURE 13.—Joint probability chart combining probabilities obtained from figures 11 and 12. Isopleths show probability of drop 15° or greater.

another chart (fig. 12). Probabilities of 15° drops were computed on these charts and isopleths of probability drawn. The probabilities of a 15° drop obtained from figures 11 and 12 were used as coordinates and the temperature change again plotted, probabilities of a 15° drop computed, and isopleths drawn resulting in figure 13.

Figure 13 was tested in the same manner as figure 10. Probabilities of a 15° drop were obtained for the 165 cases of test data and grouped into five classes of probability. The expected number of 15° drops in each class interval is compared with the observed number in table 5.[2]

[2] A Chi square test was made on this table with the same results as were obtained for the 10° drops.

TABLE 5.—*Comparison of expected and observed number of 15° drops in class intervals of computed probability of 15° drops. Values are from "test data"*

Class intervals of objectively estimated probability of a 15° drop in temperature (percent)	Number of cases in each class	Approximate number of 15° drops expected in each class	Number of observed 15° drops in each class
0–19	95	10	6
20–39	26	8	4
40–59	17	9	9
60–79	14	10	11
80–99	13	12	10

TWENTY-DEGREE DROPS

Approximately 90 percent of 20° drops in temperature result from a cold front passage. Therefore, only Criterion 1 and Criterion 2 (a) need be applied to separate the data into two groups in which the probability of a 20° drop in one is considerably larger than in the other. Of the 414 original cases, 83 met both Criterion 1 and Criterion 2 (a). Of the 26 cases in which a 20° drop was observed, 22 are included in these 83 "cold front" cases. Thus, the probability that a 20° drop will occur if the case does not meet both criteria is about 1 percent whereas the probability that a 20° drop will occur if both criteria are satisfied is about 27 percent. Only the 83 "cold front" cases were considered in further development of probability charts for 20° drops.

The same variables were again used and the same procedure followed as for the 10° and 15° drops. Figure 14 shows the isopleths of probability of a 20° drop using the Washington temperature and the temperature difference between Washington and Fort Wayne as coordinates, and in figure 15 the pressure indices computed from figure 8 are used as coordinates. In figure 16 probabilities estimated from the isopleths of figures 14 and 15 are used as coordinates and new isopleths drawn which give the final estimate of the probability of a 20° drop.

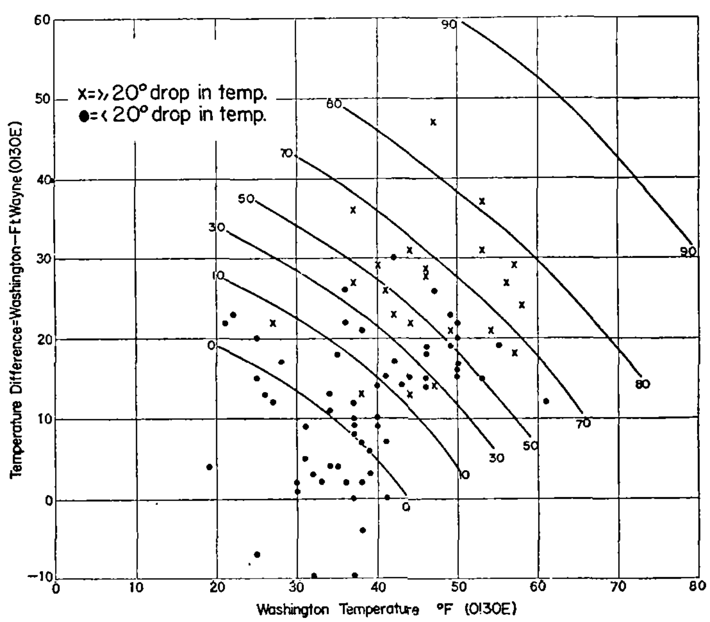

FIGURE 14.—Graph showing isopleths of probability of a drop of 20° or greater based on 0130 E. S. T. temperature difference between Fort Wayne and Washington and the 0130 E. S. T. Washington temperature. Only those cases in which a cold front lay between Norfolk and Chicago or between Norfolk and Alpena were used.

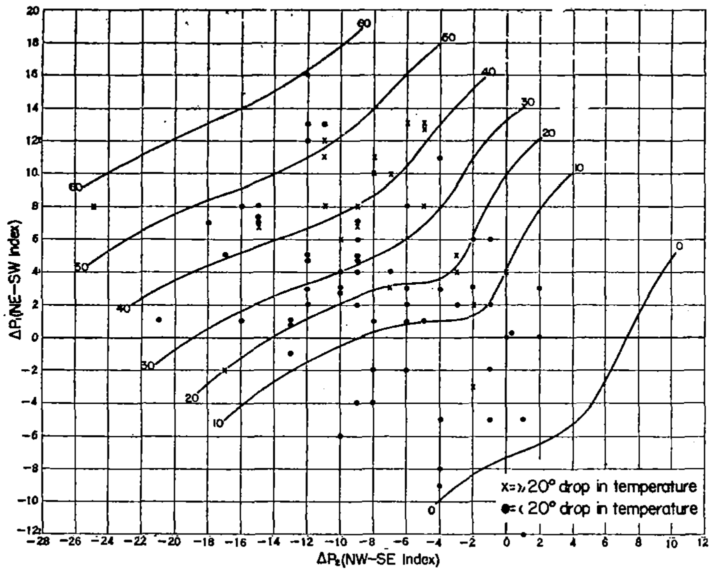

FIGURE 15.—Graph showing isopleths of probability of a drop of 20° or greater based on pressure indices computed by method shown in figure 8.

x=≥ 20° drop in temperature

●=< 20° drop in temperature

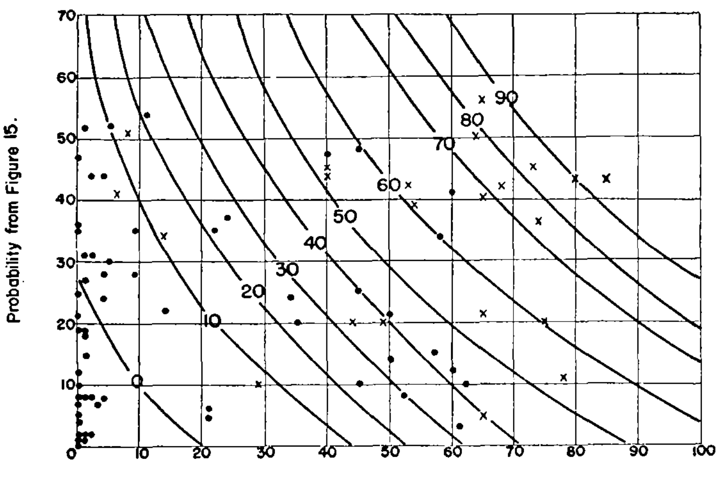

FIGURE 16.—Joint probability chart combining probabilities obtained from figures 14 and 15. Isopleths show probability of drop of 20° or greater.

A test of figure 16 was made as for figures 10 and 13. There were 21 cases of 20° drops in the test data, 19 of which were included in 90 cold front cases which met both Criterion 1 and Criterion 2 (a). Table 6 shows the expected number of 20° drops in selected classes of probability obtained from figure 16 compared with the observed number of 20° drops in each class interval.[3]

TABLE 6.—*Comparison of expected and observed number of 20° drops in class intervals of computed probability of 20° drops. Values are from "test data"*

Class intervals of objectively estimated probability of a 20° drop in temperature (percent)	Number of cases in each class	Approximate number of 20° drops expected in each class	Number of observed 20° drops in each class
<10	56	3	4
10–49	15	4 or 5	3
50–89	16	11	9
90—>90	3	3	3

[3] A Chi square test was also made on this table with same results as obtained for 10° drops.

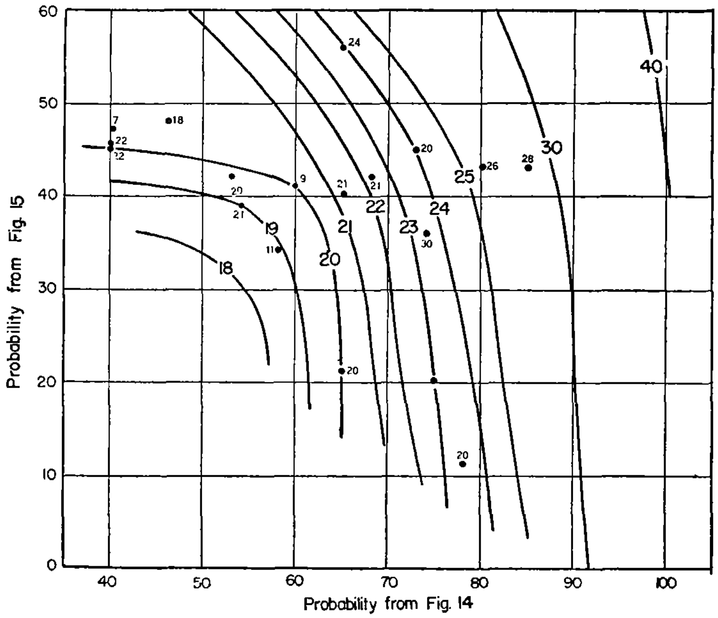

FIGURE 17.—Graph showing isograms of observed temperature change based on 50 percent or greater probabilities obtained from figures 14 and 15.

FORECASTS OF LARGE FALLS IN TEMPERATURE

DEVELOPMENT OF FORECASTING PROCEDURES

A probability statement does not give a "yes" or "no" answer as to whether an event will occur, but merely states what chance the event has of occurring under certain given conditions. In order to make a definite forecast as to whether or not the event will occur, some level of probability must be chosen as a dividing value. The 50 percent level is ordinarily adopted, and that value is used here. A 10° drop was forecasted if the probability of a 10° drop was 50 percent or greater, and similarly for 15° and 20° drops. An estimate of the actual change in temperature was made in the following manner: Those cases in which the probability of a 20° drop was 50 percent or greater were replotted using the same coordinates as figure 16. Isograms of temperature change were drawn to fit the plotted data resulting in the pattern in figure 17. The mean residual for the values plotted on this chart is 2.6°.

A similar procedure was followed for those cases in which the probability from figure 13 of a 15° drop was 50 percent or greater (excluding the cases in which the probability of a 20° drop was greater than 50 percent). The temperature change was plotted using the same coordinates as in figure 13. There was no gradient discernible on this chart, but the variability of the temperature change in this group of cases was quite small and a reasonable forecast of the change could be made by forecasting the mean value of 16°. The mean residual for these cases when a change of 16° was forecasted was 3.0°.

The same procedure was followed for those cases in which the probability of a 10° drop was 50 percent or greater (excluding the cases in which the probability of a 15° drop was greater than 50 percent). The temperature change was plotted using the coordinates of figure 10. Here again no definite gradient of temperature change existed, but the variability of the values was small enough so that a reasonable forecast of the temperature change could be made by forecasting the mean value of 13°. The mean residual for these cases when a change of 13° was forecasted was 4.3°.

The temperature changes for the cases in which the probability of a 10° drop was less than 50 percent were also plotted using the coordinates of figure 10. While a definite gradient of temperature change existed when average values were computed over the chart, the variability of the data was so great that the residuals were much too large to be considered satisfactory. This might have been expected, since the variables used for forecasting large temperature drops have not been those which would have been selected for forecasting when small changes or large rises are expected. Therefore, the actual change is estimated only when a drop of 10° or greater is forecasted, or in other words when the probability of a drop of 10° is 50 percent or greater.

TESTS OF FORECASTING PROCEDURES ON INDEPENDENT DATA

When the above procedures were applied to the "test" data the results given in table 7 were obtained.

TABLE 7.—*Summary of errors in "objective" forecasts of actual temperature fall for cases in which the computed probability of a fall of at least 10° was 50 percent or greater. Values are from "test data"*

Computed probability	Number of cases	Average error	Average change	Percent of error within 5°	Extreme error
		° F.	*° F.*	*Percent*	*° F.*
≧50 percent probability of a 20° drop	18	4.1	24	72	15
≧50 percent probability of 15° drop but <50 percent probability of 20° drop	17	3.5	15	88	−16
≧50 percent probability of 10° drop but <50 percent probability of 15° drop	36	3.9	13	75	17
Total	71	3.9	16	77	17

Since a drop in temperature of at least 10° is automatically forecasted when the probability from figure 10 is 50 percent or greater, and similarly for 15° and 20° drops, the skill with which these procedures forecast 10° or greater, 15° or greater, and 20° or greater drops can be evaluated. A 10° drop was forecasted if the case met all three criteria and the probability from figure 10 was 50 percent or greater. From table 3 it is seen that there were nine cases of test data in which the observed drop was 10° or greater, but which did not meet all three criteria. Of the 74 cases of 10° drops which met all three criteria, there were 13 in which the probability from figure 10 was less than 50 percent, making a total of 22 cases of 10° drops which were forecasted incorrectly. The forecasts of 10° drops are summarized in figure 18 (a). The skill score [4] on these forecasts is 0.72.

A 15° or greater drop was forecasted if the case satisfied all three criteria and the probability from figure 13 was 50 percent or greater. One case in which a 15° drop occurred did not meet all three criteria, and there were 12 cases in which the probability from figure 13 was less than 50 percent, making 13 cases of 15° drops not forecasted correctly. The forecasts of 15° drops are summarized in figure 18 (b). The skill score on these forecasts is .71.

A 20° drop in temperature was forecasted if figure 17 indicated a 20° or greater drop. To arrive at figure 17, however, the case had to satisfy Criteria 1 and 2 (a), and the probability from figure 16 had to be 50 percent or greater. Of the 21 cases in which a 20° drop was observed, 2 cases did not meet Criteria 1 and 2 (a), and in 7 cases the probability from figure 16 was less than 50 percent, making 9 cases of 20° drops not forecasted correctly. The forecasts of 20° drops are summarized in figure 18 (c). The skill score on these forecasts is .63.

COMPARISON OF OBJECTIVE FORECASTS WITH OFFICIAL FORECASTS

For comparison purposes, the official Weather Bureau forecasts of the minimum temperature made from the 0130 E. S. T. observations for the following night were obtained for the 361 cases of test data and converted into a forecast of the temperature change from the 0130 E. S. T. temperature to the minimum the following night. The forecasts were then verified strictly on a "yes" or "no" basis as to whether a drop of 10° or greater, 15° or greater, and 20° or greater was forecasted. For example, in verifying forecasts of 10° drops a forecast of a 9° drop was wrong if the actual drop was 10°, whereas, a forecast of a 25° drop was correct if the actual drop was only 10°.

Figure 18 (d) summarizes the official forecasts of 10° drops. Of the 83 10° drops which occurred, 63 were forecasted correctly (3 more than the objective forecasts), but a 10° drop was forecasted 27 times when it did not occur (16 more than the objective forecasts). The skill score on these forecasts is .64.

Figure 18 (e) summarizes the official forecasts of 15° or greater drops. Of the 41 cases which dropped 15°, 31 were forecast correctly (3 more than objective forecasts), while a 15° drop was forecasted 15 times when it did not occur (8 more than the objective forecasts). The skill score on these forecasts is .67.

Figure 18 (f) summarizes the official forecasts of 20° or greater drops. Of the 21 cases which dropped 20° or more, 13 were forecast correctly (1 more than objective forecasts) while a 20° drop was forecast 4 times when it did not occur (same as the objective). The skill score on these forecasts is .67.

Table 8 shows the results when the errors in the official forecasts of the actual minimum temperature are evaluated. Only the 71 cases in which an objective forecast was made are listed to compare with table 7.

TABLE 8.—*Summary of errors in "official" forecasts of actual temperature fall in cases in which the computed probability of a fall of at least 10° was 50 percent or greater. Forecasts were for same cases as are summarized in table 7*

Computed probability	Number of cases	Average error	Average change	Percent of errors within 5°	Extreme error
		°F.	*°F.*	*Percent*	*°F.*
≧50 percent probability of a 20° drop	18	3.7	24	78	8
≧50 percent probability of 15° drop but <50 percent probability of 20° drop	17	3.7	15	76	10
≧50 percent probability of 10° drop but <50 percent probability of 15° drop	36	4.2	13	61	12
Total	71	4.0	16	69	12

A comparison of tables 7 and 8 shows that the objective forecast has essentially the same average error as the official forecast and has a higher percentage of small errors, but tends to make larger errors than the official when it does fail.

[4] Skill Scores were computed from the formula:

$$\text{Skill Score}=\frac{C-E_e}{T-E_e}$$

where C=number of correct forecasts
T=total number of forecasts
E_e=expected number of correct forecasts based on the marginal totals of the contingency table.

For example in the table below:

$C=a+d$
T=Total forecasts$=(a+b+c+d)$
$$E_e=\frac{(a+b)\,(a+c)+(c+d)\,(b+d)}{T}$$

		Forecast of Event: Yes	Forecast of Event: No	
Observed Event	Yes	a	b	$a+b$
	No	c	d	$c+d$
		$a+c$	$b+d$	Total

OBJECTIVE FORECASTS

Fcst. Temp. Fall

Obs. Temp. Fall	≥10°	<10°	
≥10°	60	23	83
<10°	11	267	278
	71	290	361

Skill Score = .72 %Correct = 91

(a)

Fcst. Temp. Fall

Obs. Temp. Fall	≥15°	<15°	
≥15°	28	13	41
<15°	7	313	320
	35	326	361

Skill Score = .71 %Correct = 95

(b)

Fcst. Temp. Fall

Obs. Temp. Fall	≥20°	<20°	
≥20°	12	9	21
<20°	4	336	340
	16	345	361

Skill Score = .63 %Correct = 96

(c)

OFFICIAL FORECASTS

Fcst. Temp. Fall

Obs. Temp. Fall	≥10°	<10°	
≥10°	63	20	83
<10°	27	251	278
	90	271	361

Skill Score = .64 %Correct = 87

(d)

Fcst. Temp. Fall

Obs. Temp. Fall	≥15°	<15°	
≥15°	31	10	41
<15°	15	305	320
	46	315	361

Skill Score = .67 %Correct = 93

(e)

Fcst. Temp. Fall

Obs. Temp. Fall	≥20°	<20°	
≥20°	13	8	21
<20°	4	336	340
	17	344	361

Skill Score = .67 %Correct = 97

(f)

FIGURE 18.—Contingency tables showing comparison between "objective" and "official" forecasts of large falls in temperature at Washington, D. C.

SUMMARY

A large fall in temperature is defined as a drop of 10° or greater from the 0130 E. S. T. temperature to the minimum the following night. The following is a summary of the steps to be followed to arrive at a probability statement of a large drop in temperature and an estimate of the actual drop if the probability is greater than 50 percent.

1. Three criteria based on the pressure distribution and location of cold fronts on the 0130 E. S. T. surface chart must be met before a large drop is considered likely. If all three criteria are not satisfied, the probability of a drop of as much as 10° is approximately 4 percent.
2. If all three criteria are satisfied:
   a. The 0130 E. S. T. temperature at Washington and Fort Wayne are obtained. If the case is one in which Fort Wayne is just to the east or south of a cold front, the temperature at Fort Wayne is not used. Instead, if the front has an east-west orientation and lies between Fort Wayne and Alpena, the temperature at a point along a normal to the front from Washington at a distance equal to the distance between Washington and Fort Wayne is substituted for the Fort Wayne temperature. If the front has a north-south orientation and lies between Fort Wayne and Chicago the temperature at Madison is substituted for the Fort Wayne temperature.
   b. Pressure differences are computed as illustrated in figure 8.
   c. Figure 7 is entered with the Washington temperature and the temperature difference between Washington and Fort Wayne, and a probability estimated from the isopleths.
   d. Figure 9 is entered with the pressure differences computed from Figure 8, and a probability estimated from the isopleths.
   e. Figure 10 is entered with the probabilities obtained from figures 7 and 9, and the final probability of a 10° drop estimated from the isopleths.
   f. Using the same variables as above, figures 11, 12, and 13, are used to obtain the probability of a 15° drop.
   g. If the case is one in which a cold front exists between Norfolk and either Chicago or Alpena, then the same variables as above are used to enter figures 14, 15, and 16 to obtain the probability of a 20° drop. If the case is one in which no cold front exists, the probability of a 20° drop is only about 1 percent.
3. Estimating the actual drop.
   a. If the probability of a 20° drop is 50 percent or greater, enter figure 17 with the probabilities obtained from figures 14 and 15 and read off the estimate of the actual drop from the isograms.
   b. If the probability of a 15° drop is 50 percent or greater, but the probability of a 20° drop is less than 50 percent, forecast 16° as the temperature drop.
   c. If the probability of a 10° drop is 50 percent or greater, but the probability of a 15° drop is less than 50 percent, forecast 13° for the temperature drop.

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